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REPORT No. 226

CHARACTERISTICS OF A BOAT TYPE SEAPLANE DURING TAKE-OFF

By J. W. CROWLEY, Jr., and K. M. RONAN

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.).
Time	t	second	sec	second (or hour)	sec. (or hr.).
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		m/sec		mi./hr	M. P. H.

2. GENERAL SYMBOLS, ETC.

Weight, $W=mg$.

Standard acceleration of gravity, $g=9.80665\text{m/sec}^2=32.1740\text{ft./sec.}^2$

Mass, $m=\frac{W}{g}$

Density (mass per unit volume), ρ

Standard density of dry air, 0.12497 (kg-m^{-4}-sec^2) at 15°C and 760 mm$=$0.002378 (lb.-ft.$^{-4}$-sec.^{2})

Specific weight of "standard" air, 1.2255 kg/m^3 $=0.07651$ lb./ft.^{3}

Moment of inertia, mk^2 (indicate axis of the radius of gyration, k, by proper subscript)

Area, S; wing area, S_w, etc.

Gap, G.

Span, b; chord length, c.

Aspect ratio$=b/c$.

Distance from $c.\ g.$ to elevator hinge, f.

Coefficient of viscosity, μ.

3. AERODYNAMICAL SYMBOLS

True airspeed, V.

Dynamic (or impact) pressure, $q=\frac{1}{2}\rho V^2$

Lift, L; absolute coefficient $C_L=\frac{L}{qS}$

Drag, D; absolute coefficient $C_D=\frac{D}{qS}$

Cross-wind force, C; absolute coefficient $C_c=\frac{C}{qS}$

Resultant force, R.

(Note that these coefficients are twice as large as the old coefficients L_c, D_c.)

Angle of setting of wings (relative to thrust line), i_w.

Angle of stabilizer setting with reference to thrust line, i_t.

Dihedral angle, γ.

Reynolds Number$=\rho\frac{Vl}{\mu}$ where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr., normal pressure, 0°C: 255,000 and at 15°C, 230,000;

or for a model of 10 cm chord, 40 m/sec, corresponding numbers are 299,000 and 270,000.

Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length), C_p.

Angle of stabilizer setting with reference to lower wing. $(i_t-i_w)=\beta$.

Angle of attack, α.

Angle of downwash, ϵ.

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CHARACTERISTICS OF A BOAT TYPE SEAPLANE DURING TAKE-OFF

By J. W. Crowley, Jr., and K. M. Ronan

SUMMARY

This report, on the planing and get-away characteristics of the *F-5-L*, gives the results of the second of a series of take-off tests on three different seaplanes conducted by the National Advisory Committee for Aeronautics at the suggestion of the Bureau of Aeronautics, Navy Department. The single-float seaplane was the first tested (Reference 1) and the twin-float seaplane is to be the third.

The characteristics of the boat type were found to be similar to the single float, the main difference being the increased sluggishness and the relatively larger planing resistance of the larger seaplane. At a water speed of 15 miles per hour the seaplane trims aft to about 12° and remains in this angular position while plowing. At 22.5 miles per hour the planing stage is started and the planing angle is immediately lowered to about 10°. As the velocity increases the longitudinal control becomes more effective but overcontrol will produce instability. At the get-away the range of angle of attack is 19° to 11° with velocities from the stalling speed through about 25 per cent of the speed range.

INTRODUCTION

Seaplanes with a hull of the boat type are generally used for weight-carrying purposes. They usually have large wing and power loadings and a small reserve power. The water resistance of a hull while carrying a major portion of the seaplane's weight will necessarily be large and as the efficiency of the propeller is then low the reserve thrust at the peak resistance is seldom large. If, therefore, the planing characteristics of a new design are inferior the boat-type seaplane will require an excessively long run or may even be unable to get away under unfavorable conditions. It is believed that the information contained in this report will prove of considerable value in aiding the designer in the testing and selecting of a suitable seaplane hull.

The seaworthiness of the *F-5-L* makes it admirably fitted for a planing test as it is certainly better to be able to study the characteristics without discounting for objectional serviceable features. The *F-5-L* will weather and get away in as rough a sea as any other seaplane of its size; it will not dive at low speeds nor porpoise at high speeds. In fact, one believes it is probably even a little too statically stable than compatible with ease in breaking loose from smooth water when heavily loaded and it is too sluggish for damping the pitching set up by waves, although this might also be attributed to the inefficient unbalanced elevators, the effective use of which requires a large force. In general the more recent weight-carrying seaplanes have smaller power loadings and larger wing and float loadings. The effect of the large power loading of the *F-5-L* is favorable for amplifying its characteristics (see appendix) while the effect of a greater weight for the same wing and float area is usually to require an increase in the water speed for the various stages.

As will be explained later, the test is not as truly characteristic of the *F-5-L* as was desired and if compared specifically with model tests of the *F-5-L*, judgment should be exercised in formulating any criteria in the relations of model tests to the full scale. However, it is believed that the results as noted with reservations are quite representative.

METHODS AND APPARATUS

A synchronized time-history record of air speed, water speed, and planing angles was obtained for as varied take-off conditions as possible. Before the desired number of check runs and additional water speed and angle of attack calibrations were obtained the seaplane threw a propeller and damaged the wings to such an extent that it was necessary to dismantle it. It was not deemed worth while to reinstall the apparatus in another seaplane, nor was this possible as there was not another one available at that time.

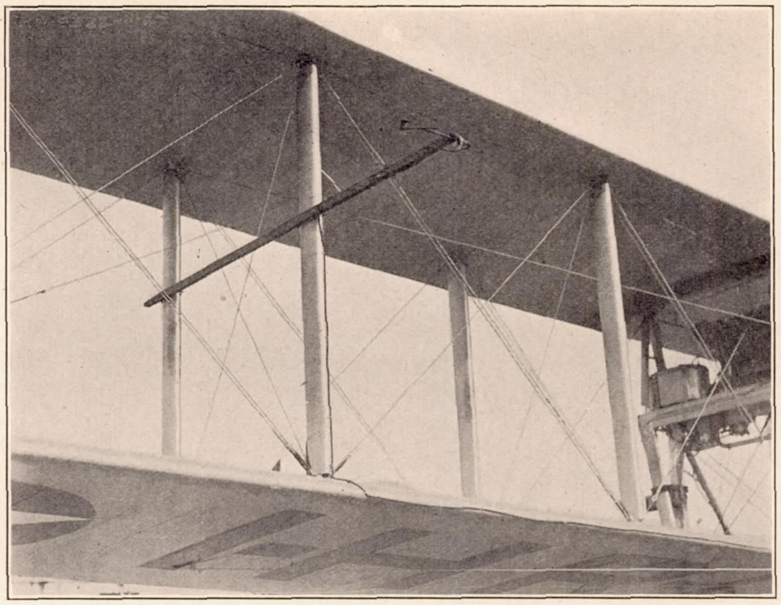

FIG. 1.—Mounting of vane for determining planing angle

The air speed was indicated by a Baden double-Venturi meter and a N. A. C. A. air speed recorder. (Reference 2.) The indicating accuracy of the Venturi head is not as good as that of a Pitot-static head, but due to the larger pressure difference given by it the accuracy of reading low speeds is considerably increased.

The planing angles were obtained by a vane, mounted on a boom extending ahead of the wings (fig. 1), which was free to align itself with the relative wind. The position of the vane was recorded by a special galvanometer, (Reference 3) mounted in the cockpit, to which the vane was electrically connected.

The water speed was measured by a Pitot tube extended through a breather hole aft of the rear step (fig. 2). This was lowered into position after the seaplane was on the water. Due to the sharp V bottom the tube had to be extended 2 feet below the breather hole to be below the keel. Even when the tube was made of ¼-inch hydraulic tubing it was permanently deflected by the landing impact, so that it had to be braced by a cable from the front breather hole. The resistance of the tube and cable was considerable at high speeds. This was emphasized on a calm day, when with a total weight of 14,200 pounds (1,200 pounds overload) the seaplane could not get off with the water speed apparatus lowered. From previous and subsequent experience it has been found that a short Pitot tube extended below the keel makes the best type of water speed head. On the *F-5-L* the use of such a tube fixed on the keel was impossible, due to launching difficulties, while a tube which could be lowered

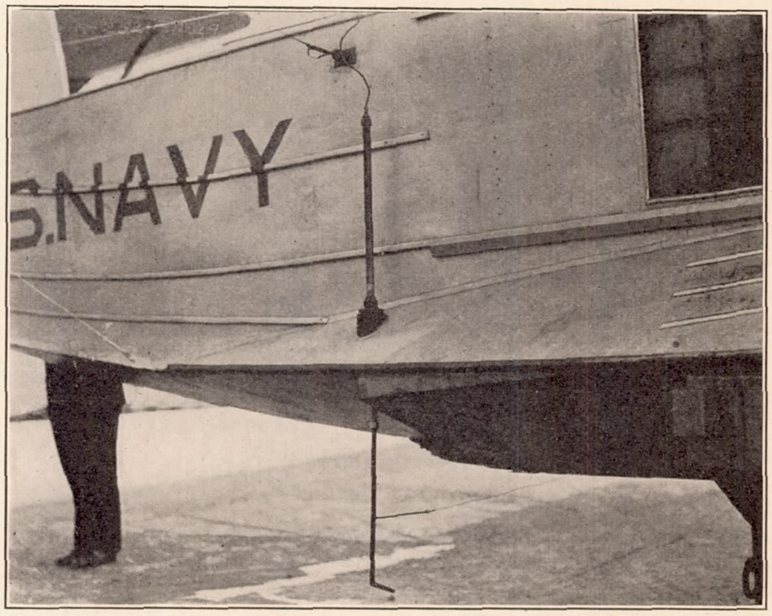

FIG. 2.—Water speed head lowered into position

through the keel after launching was impracticable because of the structural work necessary, so that the breather hole was used as previously mentioned. Two low-speed points on the water speed calibration curve were obtained by taxying over a measured course. These showed the indicated water speed to be slightly high. It was assumed that this effect would be lessened as the float raised in the water and the results are corrected accordingly.

To ascertain the natural characteristics, the amount of controllability, and the effects of different control moments, four piloting methods were used. These are designated on the curves as control free, control forward, control back, and normal. Nearly every pilot has a slightly different method of making a take-off, which is also subject to some change depending upon the conditions of load, water, wind, etc. It is therefore very difficult to describe what may be considered a universal method of making a normal take-off. The following description of a normal take-off was made by a pilot of wide experience in naval aeronautics, but as will be noted later this is not entirely similar to the normal method used by the pilots on this investigation: "Give the engine full throttle, hold some up elevator until headway is on, then pull up the elevator until the bow wave moves back to the pilot's seat. The seaplane should now have started planing. As soon as this is appreciably noticeable ease forward on the control, and as planing increases force the nose forward to break the step clear, then ease back on the control, and as the speed increases pull back, harder and harder, and the seaplane should fly off. If the drag is too great, or the seaplane unusually heavy, it may be necessary to flip the nose up, and ease the control forward, but do not rock. Several pulls may be necessary, but each will result in an increase of speed."

PRECISION

The precision to be expected is as follows:

Air speed	±1 mile per hour.
Water speed	±1.5 miles per hour.
Angle	±1°.
Time synchronization	±0.5 second.

RESULTS

The time consumed for passing through the different stages and the time comparison of the different take-off methods have not been stressed because of the additional drag imposed in measuring the water speed and also, as previously mentioned, because of the inability to obtain sufficient check runs. The records have been studied with the idea of ascertaining general planing characteristics, such as the variation in angle and stability with velocity and control and a few evident resistance characteristics.

The results are contained in Figures 3 to 14. Figures 3 to 12 are records of the individual runs, and Figures 13 and 14 are summaries from the original. The point (*a*) where the water lift begins to become rapidly dynamic rather than buoyant, and thus starts the float to rise out of the water, and the point (*b*) where this process is nearly completed and the planing begins are noted by the terms "rising to step" and "planing on step," respectively. The point (*c*) where the float clears the water is noted as "take-off." The condition "planing on step" is not as well defined in the boat type seaplane as it is in the single-float type. It is believed that this is the effect of the more acute V bottom, necessitating immersing the lower part of the V in order to obtain the required lift, and thus preventing the clean planing characteristics of a flatter bottom (Reference 4). In this connection it was noticed that an unusually large turbulent wave of water at right angles to the front step was carried along throughout both the plowing and planing stages. This does not refer to the thin blister or spray of water thrown up from under the chine which is characteristic of all V bottoms. The disturbance in this region must cause considerable resistance.

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Figures 3 and 4 show runs made with the control free. The angle assumed by a seaplane is determined by the combination of the planing balance and the air balance. The *F-5-L* does not have an adjustable stabilizer so that it is balanced for normal flying angles. If a seaplane's weights are adjusted correctly so that it will plane stably it is quite likely to align itself along a line parallel to the line of the two steps, which on the *F-5-L* is about 7½° to the longitudinal axis. This angle is slightly greater than the cruising air balance and smaller than the

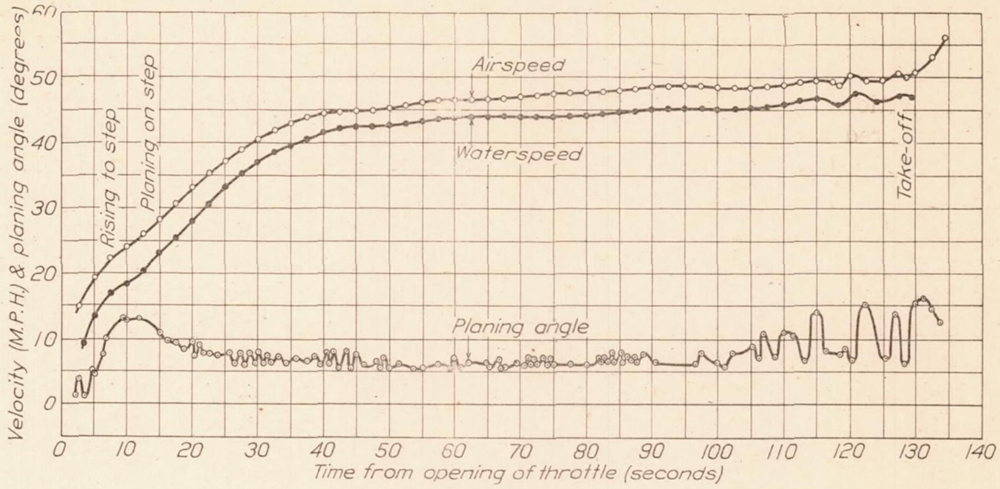

FIG. 3.—Method—Control free
(NOTE.—Pilot had to rock seaplane to get off)

average get-away angle. The run shown in Figure 3 made on smooth water shows that the *F-5-L* planes stably at about 7°. Oscillations are shown to build up slightly and then damp out. It is reasonable to suppose that the hull alone is slightly unstable while planing in smooth water but that the tail surfaces and wings counteract this instability. This feature, however, is not present on slightly rippled water, as is shown in Figure 4, and a slightly lower mean planing angle is maintained. These two characteristics were also evident on the single-float type. This instability is a favorable characteristic, as a float that is slightly unstable is liable to require a smaller moment to change the trim than a stable one. As shown in Figure 3, the pilot first

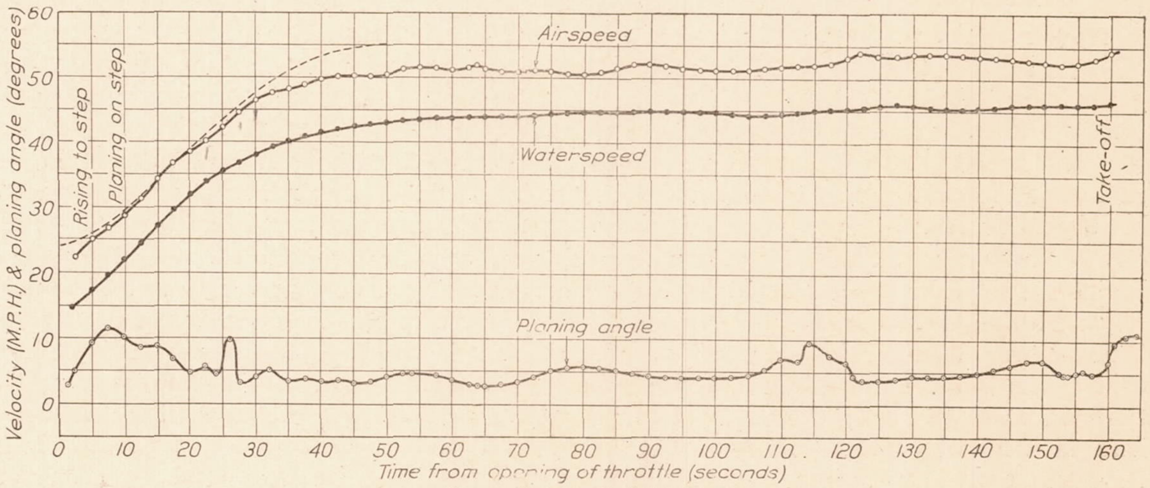

FIG. 4.—Method—Control free
(NOTE.—Pilot had to "pull seaplane off")

pulled the control back, but could not bring it to a high enough angle to get off, and then resorted to rocking. This inability to get off easily when heavily loaded on smooth water may be due, it has been suggested, to the insufficient curvature aft of the rear step. The amplitude of these oscillations shows clearly the ability to rock this seaplane through a large angular range. In the run shown in Figure 4 the increased air speed enabled a get-away to be made by pulling back on the control. It is noted that the seaplane rose to the step on smooth water even with

full load as quickly as if it had been assisted by "rocking." This was not true of the single-float seaplane.

One would think that if a seaplane would not get off with control free it would not do so by pushing the control forward. But Figure 5 shows this to be possible. In this particular run as soon as planing started large damped oscillations were set up, which became so violent toward the end that the pilot pulled back on the control and took off. It is quite probable

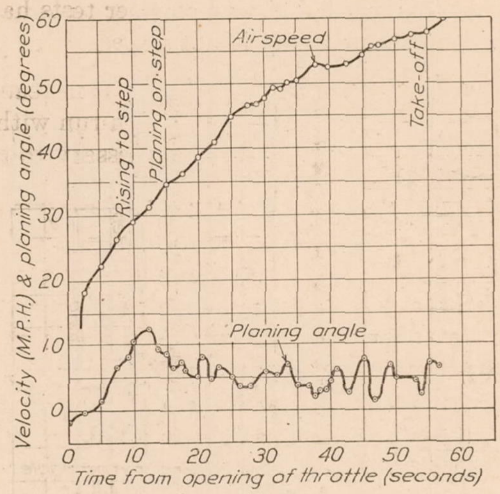

FIG. 5.—Method—Control forward
(NOTE.—Pilot "pulled seaplane off")

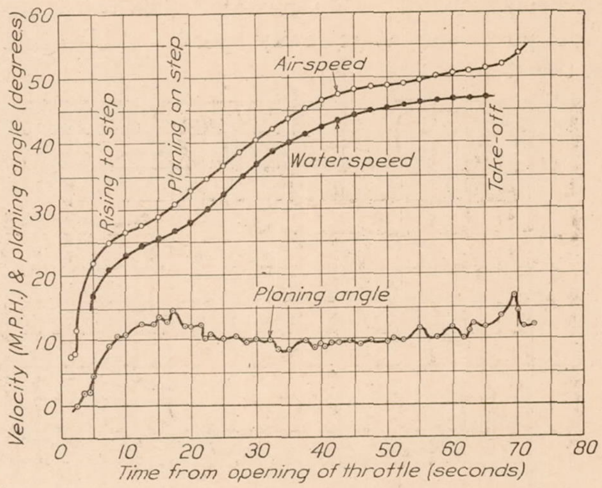

FIG. 6.—Method—Control back

that if he had kept the control forward the seaplane would have jumped out of the water during its oscillations. This is an example of porpoising often occurring in some seaplanes at high planing speeds, which is caused, as in this run, by the bow being held on the water. The inherent porpoising may be attributed to the same condition, but is brought about either by the center of gravity being located too far from the step or by a poor float form. Such was the case with an amphibian boat which has a tail skid extending below the keel aft of the rear step. This seaplane porpoised badly and it is believed that it was mainly due to the tail skid's tendency to hold the bow deeper in the water than it normally would have planed. Again noticing the

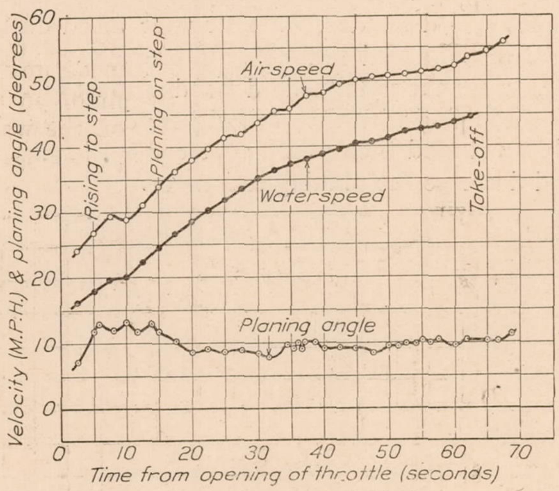

FIG. 7.—Method—Control back

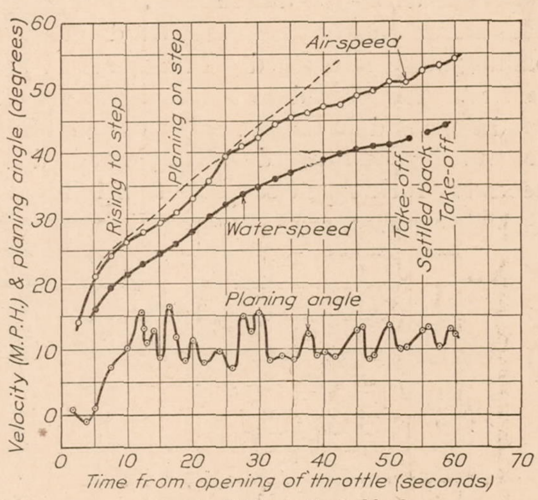

FIG. 8.—Method—Control back

curves of Figure 5, it will be seen that the *F-5-L* rose to the step without reaching as high an angle as by the other methods, and although the "start to rise" point was perhaps somewhat delayed it passed through this transient stage to the planing condition in about the same time. The water speed was not secured on this run.

In Figures 6, 7, and 8 curves of runs made withthe control held back are plotted. The run pictured in Figure 6 was made on very smooth glassy water. A high angle was maintained

throughout without any appreciable oscillations until a water speed of 45 miles per hour was reached. Figure 7 shows another rather similar run taken on rippled water. In Figure 8 is shown a run made on smooth water which has large oscillations throughout. Other tests have shown that holding the control back is quite likely to bring porpoising at a lowered speed, as in Figure 6, but not to cause it at all speeds. It is therefore believed that there was a misunderstanding between the pilot and the observer concerning this run and that this is in reality a normal take-off. Discounting Figure 8, it is seen that this method gives a smooth run with a slight porpoising at get-away speeds. It is again evident that rocking is not necessary to get on the step.

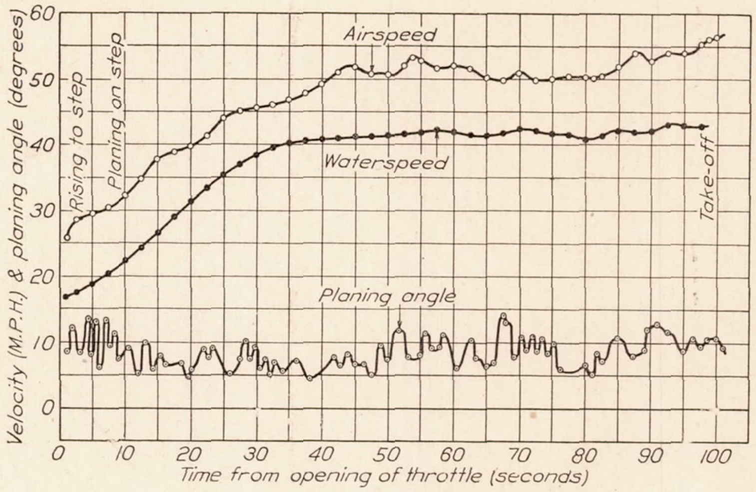

FIG. 9.—Method—Normal

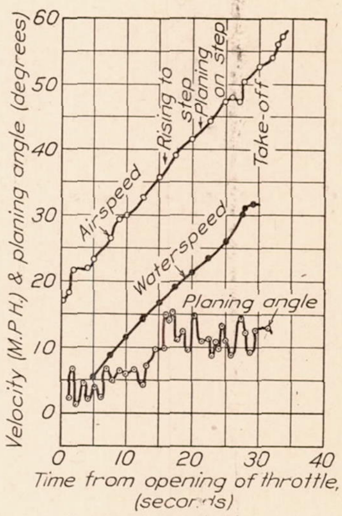

FIG. 10.—Method—Normal

The curves of the normal method shown in Figures 9, 10, 11, and 12 have few similarities. The load on the run shown in Figure 9 was 14,200 pounds and the pilot had extreme difficulty in getting off, and it appears that he rocked the seaplane throughout. Figure 10 shows a normal run taken in choppy water, and it is recalled that the oscillations are more due to the waves than to the controls. In this run "rising to step" and "planing on step" occur at the usual water speeds of 17 and 22 miles per hour, while the air speeds are nearly 20 miles per hour higher. This shows clearly that the attitude of the seaplane is dependent on the water speed until a planing stage is reached. In Figures 11 and 12 are pictured take-offs quite common in the service. The procedure is rocking to get on the step, the amplitude depending on the water conditions and on the success of the pilot in synchronizing with the natural period, pushing the control slightly forward until flying speed is obtained, and then pulling the control back, or if necessary rocking the seaplane to help lift it and decrease the planing resistance.

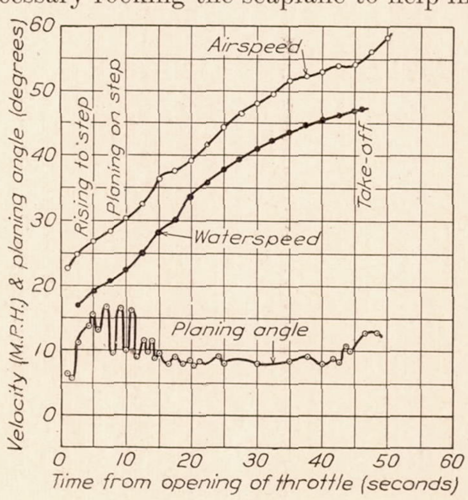

FIG. 11.—Method—Normal

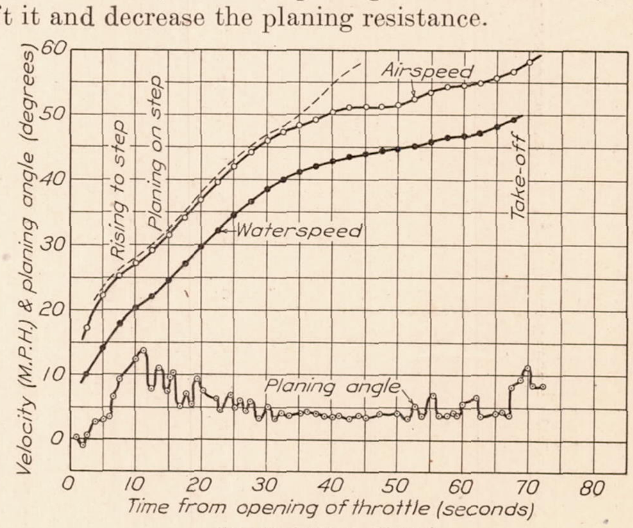

FIG. 12.—Method—Normal

In Figures 4, 8, and 12 are dotted-line curves of air speed taken on similar runs without the water speed apparatus. It is noticeable on these that the slopes of the curves are nearly the same throughout a run, showing only a little flattening out at hump speed. This point of minimum acceleration or maximum resistance occurs between the water speeds of 17.5 and 22.5 miles per hour. The acceleration through this transient stage is fairly good but the pick-up thereafter is poor. As mentioned before, it is believed that this planing quality is due to the high resistance of the V bottom. (Reference 5.) A compromise between the shock-absorbing qualities of the sharp V bottom and the planing and taxying advantages of the flat bottom has been advanced. (See Reference 4.) This consists in flattening the keel line of the conventional V bottom. If this compromise is unsatisfactory, it seems possible that the shock-absorbing qualities of the sharp V could be replaced by some mechanical means. For obtaining quickly a knowledge of the planing performance, a take-off history of the angle and air speed will give the desired information. Due to the mechanical difficulties involved, with this type of hull, the securing of water speed is not worth while except for extensive research.

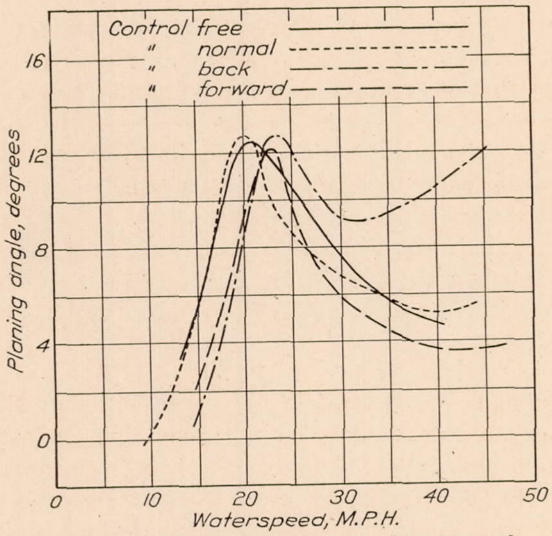

FIG. 13.—Variation in planing angle with water speed

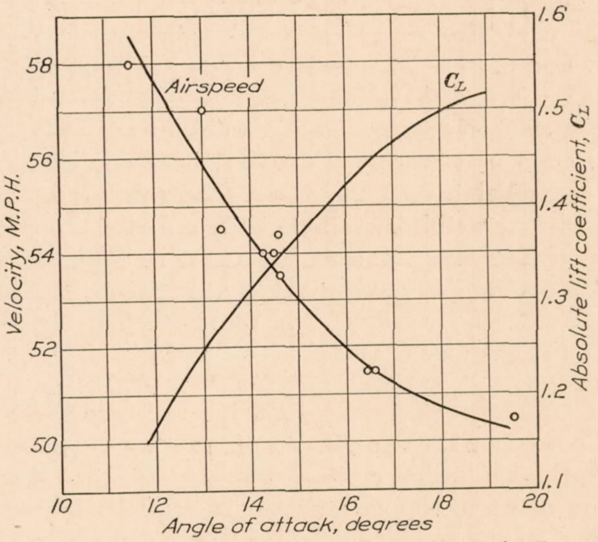

FIG. 14.—Velocity and lift coefficient at various angles of take-off

A comparison of the four methods of take-off shows that it is not necessary to rock the *F-5-L* to get on the step and little or no time is gained thereby, but rocking may be required to get off. The ability of the *F-5-L* to rise to the step when heavily loaded, regardless of the control method or water conditions, shows that it has a sufficient water-lifting area when all of the sponson or "planing fins" are immersed. The apparent necessity of rocking it on smooth waters to get away indicates that the form of its after body could be improved. It is quite desirable with a large military seaplane and very necessary with a commercial seaplane to be able to take off smoothly, as rocking is very disagreeable to passengers and it necessitates fastening everything very rigidly. The control should be used to dampen the pitching caused by waves, rather than to produce pitching. For this reason, and also to be able to raise the nose high enough to get away, a large seaplane should be provided with large horizontal control surfaces and well-balanced elevators.

The average planing angle at each water speed by the different control methods is shown in Figure 13. These curves are found from points on the original curves, but as there were only two or three runs of each condition they may not represent a true average, as the trim is somewhat affected by the water condition. It will be noticed that the peak resistance of the control back method is deferred. In the single-float tests the peaks were practically the same except for control forward. The peak resistance of the hull occurs during the high-angle period or between the water speeds of 17.5 and 22.5 miles per hour.

In Figure 14 are shown the velocities and angles of attack at the get-away. The lift curve, C_L, is derived from this curve by assuming this to be a level flight condition, although ground interference may cause it to be slightly in error. It shows that the angle of attack at the get-away varies from 11° to 19°, with velocities of 58 to 51 miles per hour. Assuming the maximum speed to be 80 miles per hour, the get-away speed range is therefore about 25 per cent of the flying speed range.

CONCLUSIONS

The maximum resistance occurring at a water speed of 17.5 to 22.5 miles per hour and at a planing angle of about 16° is only slightly greater than that occurring at lower and higher speeds. It is believed that this is due to high planing resistance rather than especially low plowing resistance. It seems desirable to reduce the planing resistance by improving the form of the middle body perhaps by flattening of the bottom ahead of the front step.

The seaplane is very stable longitudinally in water calmer than choppy water of a depth between the crest and trough of a foot. However, it is not too stable as to be uncontrollable, so that pitching caused by a rough sea can be somewhat dampened. The *F–5–L* under all conditions will get on the step and under average conditions get away as quickly as when rocking is resorted to. Its get-away speeds are 51 to 58 miles per hour at angles of attack of 19° to 11°.

The fixed stabilizer, which precludes the possibility of trimming for both get-away and cruising angles and the carrying of an unbalanced load, is an undesirable feature. In the design of the empennage on a large flying boat equal consideration should be given to the controllability on the water and in the air. For taking off, large horizontal tail surfaces with efficient well-balanced elevators are desirable, especially on a commercial seaplane.

The securing of a water speed record, without the imposition of considerable drag, on a large acute V bottom boat offers such mechanical difficulties that it is not worth while except in an extensive research. To obtain the most important planing characteristics quickly and easily a time-history of the air speed and planing angle is sufficient.

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APPENDIX [1]

Characteristics of the F-5-L Seaplanes

Type	Boat type twin-engine biplane.
Wing area	1,397 square feet.
Angle of incidence of wings	4°.
Weight, average as tested	13,700 pounds. Run No. 9, 14,200 pounds.
Engines	2 Liberty's, 2 x 360 HP. at 1,650 revolutions per minute.
Wing loading	9.8 pounds/square feet.
Power loading	19 pounds/B. HP.

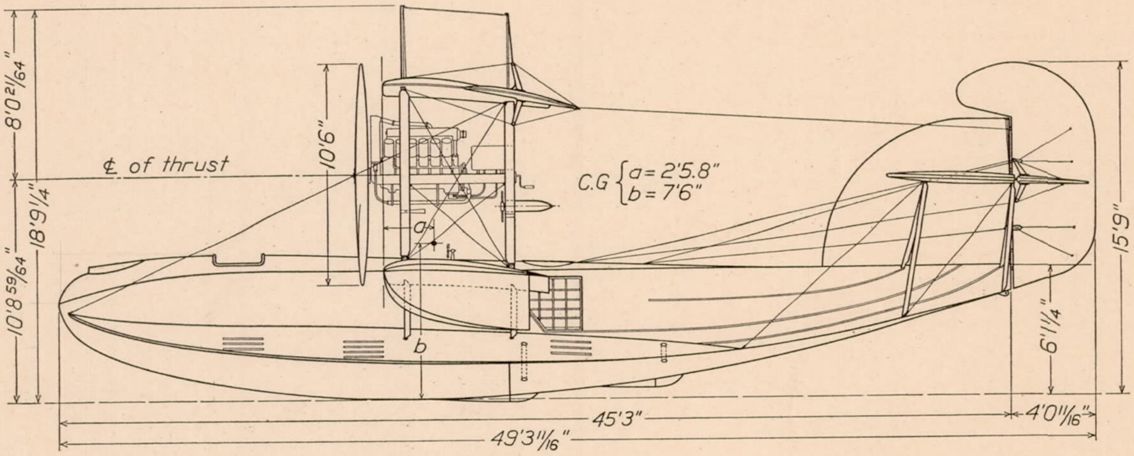
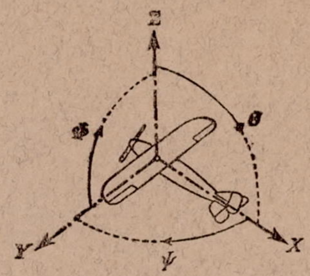


FIG. 15.—F-5-L seaplane

[1] Taken from Bureau of Aeronautics, United States Navy, performance chart.



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_l=\frac{L}{qbS} \quad C_m=\frac{M}{qcS} \quad C_n=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

Diameter, D
Pitch (a) Aerodynamic pitch, p_a
(b) Effective pitch, p_e
(c) Mean geometric pitch, p_g
(d) Virtual pitch, p_v
(e) Standard pitch, p_s
Pitch ratio, p/D
Inflow velocity, V'
Slipstream velocity, V_s

Thrust, T.
Torque, Q.
Power, P.
(If "coefficients" are introduced all units used must be consistent.)
Efficiency $\eta = T\,V/P$.
Revolutions per sec., n; per min., N.
Effective helix angle $\Phi=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP. = 76.04 kg/m/sec = 550 lb./ft./sec.
1 kg/m/sec = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec
1 m/sec = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.